

# EDAF50 – C++ Programming

## 4. *Classes*

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- 1 **Classes**
  - Constructors
  - Copying objects
  - Operator overloading
  - friend
  
- 2 **Static members**
  - Static members

# User-defined types

## Categories

- ▶ Concrete classes
- ▶ Abstract classes
- ▶ Class hierarchies

# User-defined types

## Concrete classes

### A concrete type

- ▶ “behaves just like a built-in type”
- ▶ its representation is part of its definition,  
That allows us to
  - ▶ refer to objects directly (not just using pointers or references)
  - ▶ initialize objects directly and completely (with a *constructor*)
  - ▶ place objects
    - ▶ on the stack (i.e., local variables)
    - ▶ in other objects (i.e., member variables)
    - ▶ in statically allocated memory (e.g., global variables)
  - ▶ copy objects
    - ▶ assignment of a variable
    - ▶ copy-constructing an object
    - ▶ value parameter of a function

## Default constructor

- ▶ A constructor that can be called without arguments
  - ▶ May have parameters that all have default values
- ▶ Automatically defined if *no constructor is defined* (in declaration: `=default`, cannot be called if `=delete`)
- ▶ If not defined, the type is *not default constructible*

## Default constructor with member initializer list.

```
class Bar {  
public:  
    Bar(int v=100, bool b=false) :value{v},flag{b} {}  
private:  
    int value;  
    bool flag;  
};
```

# Constructors

## Default constructor

### Default arguments

- ▶ If a constructor can be called without arguments, it is a default constructor.

```
class KomplexTal {  
public:  
    KomplexTal(float x=1):re(x),im(0) {}  
    //...  
};
```

gives the same default constructor as the explicit

```
KomplexTal():re{1},im{0} {}
```

# Constructors

## Two ways of initializing members

### With member initializer list in constructor

```
class Bar {  
public:  
    Bar(int v, bool b) : value{v}, flag{b} {}  
private:  
    int value;  
    bool flag;  
};
```

### Members can have a *default initializer*, in C++11:

```
class Foo {  
public:  
    Foo() =default;  
private:  
    int value {0};  
    bool flag {false};  
};
```

- ▶ prefer default initializer to overloaded constructors or default arguments

# Constructors

## Initialization and assignment

It is (often) *possible* to write like in Java, but

- ▶ it is less efficient
- ▶ the members must be *default constructible* and *assignable*

### Java-style: assignment in constructor

```
class Foo {  
public:  
    Foo(const Bar& v) {  
        value = v;  NB! assignment, not initialization  
    }  
private:  
    Bar value; is default constructed before the body of the constructor  
};
```

*An object is initialized before the body of the constructor is run*

```

class Foo{
public:
    Foo(int x) :x{x} {}
    // ...
private:
    int x{};
};

```

```

class Bar{
public:
    Bar(int x) {x = x;}
    // ...
private:
    int x{};
};

```

warning: explicitly assigning value of variable of type 'int'  
to itself; did you mean to assign to member 'x'?

```

[-Wself-assign]
Bar(int x) {x = x;}
           ~ ^ ~
           this->

```

# Constructors

## Member initialization rules

```
class Bar {  
public:  
    Bar() =default;  
    Bar(int v, bool b) :value{v},flag{b} {}  
private:  
    int value {0};  
    bool flag {true};  
};
```

- ▶ If a member has both *default initializer* and a member initializer in the constructor, the constructor is used.
- ▶ Members are initialized *in declaration order*. (Compiler warning if member initializers are in different order.)
- ▶ `Bar() =default;` is necessary to make the compiler generate a default constructor (as another constructor is defined)

# Constructors

## Prefer default member initializers

*Use default member initializers* if class member variables have default values.

### Default argument values and overloaded ctors: risk of inconsistency

```
class Simple {  
public:  
    Simple()                : a(1), b(2), c(3) {}  
    Simple(int aa)         : a(aa), b(0), c(0) {}  
    Simple(int aa, int bb, int cc=-1) : a(aa), b(bb), c(cc) {}  
private:  
    int a;  
    int b;  
    int c;  
};
```

# Constructors

## Prefer default member initializers

*Use default member initializers* if class member variables have default values.

### With default initializers: consistent

```
class Simple {
public:
    Simple() =default;
    Simple(int aa)           :a(aa) {}
    Simple(int aa, int bb)   :a(aa), b(bb) {}
    Simple(int aa, int bb, int cc) :a(aa), b(bb), c(cc) {}
private:
    int a {-1};
    int b {-1};
    int c {-1};
};
```

# Constructors

## Default constructor and parentheses

In a variable declaration, the default constructor *cannot be called with empty parentheses*.

```
Bar b1;  
Bar b2{};  
Bar be(); // Not a variable declaration! "most vexing parse"  
Bar b3(25); // OK  
  
Bar* bp1 = new Bar;  
Bar* bp2 = new Bar{};  
Bar* bp3 = new Bar(); //OK
```

NB! The compiler error will be at the *use* of `be` e.g.,

```
be.fun();
```

request for member 'fun' in 'be', which is of non-class type 'Bar()'

# Default constructor and initialization

- ▶ *automatically generated* default constructor (=default) *does not always* initialize members
  - ▶ *global variables* are initialized to 0 (or corresponding)
  - ▶ *local variables* are not initialized (*different meaning from Java*)

```
struct A { int x; };

int i; // i is initialized to 0 (global variable)
A a;   // a.x is initialized to 0 (global variable)

int main() {
    int j;           // j is uninitialized
    int k = int();  // k is initialized to 0
    int l{};        // l is initialized to 0

    A b;           // b.x is uninitialized
    A c = A();     // c.x is initialized to 0
    A d{};        // d.x is initialized to 0
}
```

# Default constructor and initialization

## Advice

- ▶ The *automatically generated* default constructor (`=default`) *does not always* initialize members
  
- ▶ To be on the safe side:
  - ▶ *always initialize variables*
  - ▶ *always implement default constructor (or `=delete`)*  
(incl. giving all members default initializers and use `=default`)

# Constructors

## Delegating constructors (C++11)

In C++11 a constructor can call another (like `this(...)` in Java).

```
struct Test{
    int val;

    Test(int v) :val{v} {}

    Test(int v, int scale) :Test(v*scale) {}; // delegation

    Test(int a, int b, int c) :Test(a+b+c) {}; // delegation
};
```

A delegating constructor call shall be *the only member-initializer*.  
( A constructor initializes an object *completely*.)

# User-defined types

## Concrete classes

### A concrete type

- ▶ “behaves just like a built-in type”
- ▶ the representation is part of the definition,  
That allows us to
  - ▶ place objects
    - ▶ on the stack (i.e., local variables)
    - ▶ in other objects (i.e., member variables)
    - ▶ in statically allocated memory (e.g., global variables)
  - ▶ copy objects
    - ▶ assignment of a variable
    - ▶ copy-constructing an object
    - ▶ value parameter of a function
  - ▶ refer to objects directly (not just using pointers or references)
  - ▶ initialize objects directly and completely (with a *constructor*)

## Copy Constructor

- ▶ Is called when initializing an object
- ▶ Is *not called* on assignment
- ▶ Can be defined, otherwise a standard copy constructor is generated (=default, =delete)

```
Bar b1(10, false);
```

```
Bar b2{b1};           // the copy constructor is called
```

```
Bar b3(b2);          // the copy constructor is called
```

```
Bar b4 = b2;         // the copy constructor is called
```

```
void function(Bar); // by-value parameter
```

```
function(b2);       // the copy constructor is called
```

# Copy Constructors

## default

- ▶ Declaration:

```
class C {  
public:  
    C(const C&) =default;  
};
```

- ▶ default copy constructor

- ▶ Is automatically generated if not defined in the code
  - ▶ exception: if there are members that cannot be copied
- ▶ But do declare it **=default** when you want it.
- ▶ *shallow copy* of each member
  - ▶ Works for member variables of built-in types,
  - ▶ or *classes that behave like built-in types* (RAII-types)
  - ▶ *Does not work* for classes which manage resources “manually”  
(More on this later)

# Classes

## Example: Copying the Vector class

```
class Vector{  
public:  
    Vector(int s) :sz{s},elem{new double[s]} {}  
    ~Vector() {delete[] elem;}  
    double& operator[](int i) {return elem[i];}  
    int size() {return sz;}  
private:  
    int sz;  
    double* elem;  
};
```

Vector vec:



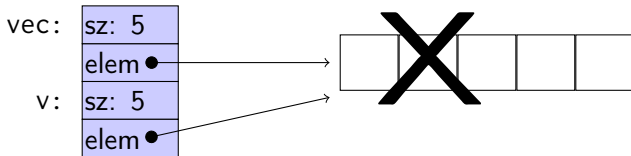
*No copy constructor defined  $\Rightarrow$  default generated.*

# Classes

## Default copy construction: shallow copy

```
void f(Vector v);

void test()
{
    Vector vec(5);
    f(vec); // call by value -> copy
    // ... other uses of vec
}
```



- ▶ The parameter `v` is default copy constructed: the value of each member variable is copied
- ▶ When `f()` returns, the destructor of `v` is executed:  
`delete[] elem;`
- ▶ The array pointed to *by both copies* is deleted. Disaster!

# Constructors

Special cases: zero or one argument

## Copy Constructor

- ▶ Has the same class as parameter: `Bar::Bar(const Bar& b);`

## Converting constructor

- ▶ A constructor that can be called with one argument defines an *implicit type conversion* from the type of the parameter

```
class ComplexNumber {  
public:  
    ComplexNumber():re{0},im{0} {}  
    ComplexNumber(const ComplexNumber& k) :re{k.re},im{k.im} {}  
    ComplexNumber(double r, double i=0):re{r},im{i} {}  
    //...  
private:  
    double re;  
    double im;  
};
```

default constructor

copy constructor

converting constructor

# Converting constructor

## Warning - implicit conversion

```
class Vector{
public:
    Vector(int s);    // create Vector with size s
    ...
    int size() const; // return size of Vector
    ...
};

void example_vector()
{
    Vector v = 7;

    std::cout << "v.size(): " << v.size() << std::endl;
}

v.size(): 7
```

In `std::vector` the corresponding constructor is declared

```
explicit vector( size_type count );
```

# Converting constructor and `explicit`

`explicit` specifies that a constructor does not allow implicit type conversion.

```
struct A                struct B
{
    A(int);             {
    // ...              explicit B(int);
};                      // ...
};

A a1(2);               // OK          B b1(2);           // OK
A a2 = 1;              // OK          B b2 = 1;         // Error! [2]
A a3 = (A)1;          // OK          B b3 = (B)1;     // OK: explicit cast

a3 = 17;              // OK [1]      b3 = 17;         // Error! [3]
```

[1]: construct an A(17), **and** then copy

[2]: conversion from 'int' to non-scalar type 'B' requested

[3]: no match for 'operator=' (operand types are 'B' and 'int')

# Copying objects

## Difference between *construction* and *assignment*

```
Bar b1(10, false);

Bar b2{b1};           // the copy constructor is called
Bar b3(b2);           // the copy constructor is called
Bar b4 = b2;         // the copy constructor is called

void function(Bar); // by-value parameter

function(b2);        // the copy constructor is called

b4 = b3;             // the copy constructor is not called
```

*copy assignment* – not construction

# Copying objects

the *copy assignment* operator: `operator=`

The *copy assignment operator* is implicitly defined

- ▶ with the type `T&` `T::operator=(const T&)`
- ▶ if no copy assignment operator is declared for the type
- ▶ if all member variables can be copied
  - ▶ i.e., define a copy-assignment operator
- ▶ If all members are of built-in (and RAII) types the default variant works (same problems as with copy ctor).
- ▶ More on copy control when we discuss resource management

- ▶ Declaration:

```
class C {  
public:  
    C(const C&) =delete;  
    C& operator=(const C&) =delete;  
};
```

- ▶ A class without copy constructor and copy assignment operator cannot be copied.
  - ▶ C++-98: declare private and don't define

# Operator overloading

*A user-defined type can behave like a built-in type*

- ▶ Operators can be overloaded
  - ▶ as member functions (sometimes)
  - ▶ as free functions

Syntax: `return_type operator⊗ (parameters...)`  
for an operator ⊗ e.g. `==` or `+`

E.g, `bool operator==(const Foo&, const Foo&);`

# Operator overloading

Most operators can be overloaded, except

`sizeof` `.` `.*` `::` `?:`

E.g., these operators can be overloaded

```
=  
+ - * / %  
^ & | ~  
<< >>  
&& || !  
!= == < >  
++ -- += *= .....  
() []  
-> ->*  
&  
new delete new[] delete[]
```

# Operator overloading

For classes, two possibilities:

- ▶ as a member function
  - ▶ for binary operators, if the order of operands is suitable
    - ▶ a binary operator takes *one argument*
    - ▶ **\*this** is the left operand,
    - ▶ the function argument is the right operand
- ▶ as a *free* function
  - ▶ if the public interface is enough, *or*
  - ▶ if the function is declared **friend**

Functions or classes with **access to all members in a class** without being members themselves

### Friend declaration in the class ComplexNumber

```
class ComplexNumber{
    //...
private:
    int re;
    int im;
    friend ostream& operator<<(ostream&, const ComplexNumber&);
};
```

### Definition of the free function operator<<

```
ostream& operator<<(ostream& o, const ComplexNumber& c) {
    return o << c.re << "+" << c.im << "i";
}
```

The free function `operator<<(ostream&, const ComplexNumber&)` can access private members in `ComplexNumber`.

Functions or classes with *full access to all members* in a class without being members themselves

- ▶ Free functions,
- ▶ member functions of other classes, or
- ▶ entire classes can be friends.
- ▶ cf. package visibility in Java
- ▶ A friend declaration is not part of the class interface, and can be placed *anywhere in the class definition*.

# Operator overloading as member function and as free function

## Example: declaration as member functions

```
class Komplex {  
public:  
    Komplex(double r, double i) : re(r), im(i) {}  
    Komplex operator+(const Komplex& rhs) const;  
    Komplex operator*(const Komplex& rhs) const;  
    // ...  
private:  
    double re, im;  
};
```

## Example: declaration of operator+ as friend

Declaration inside the class definition of Komplex:

```
friend Komplex operator+(const Komplex& l, const Komplex& r);
```

*Note the number of parameters*

# Operator overloading

Defining `operator+` in two ways:

- ▶ As member function (one parameter)

```
Komplex Komplex::operator+(const Komplex& rhs) const {  
    return Komplex(re + rhs.re, im + rhs.im);  
}
```

- ▶ As a free function (two parameters)

```
Komplex operator+(const Komplex& lhs, const Komplex& rhs) {  
    return Komplex(lhs.re + rhs.re, lhs.im + rhs.im);  
}
```

*NB! the `friend` declaration is only in the class definition*

# Operator overloading

Defining `operator+` in two ways:

- ▶ As member function

```
Komplex Komplex::operator+(const Komplex& rhs) const {  
    return Komplex(re + rhs.re, im + rhs.im);  
}
```

the right operand  
cannot be changed

the left operand  
cannot be changed

- ▶ As a free function

```
Komplex operator+(const Komplex& lhs, const Komplex& rhs) {  
    return Komplex(lhs.re + rhs.re, lhs.im + rhs.im);  
}
```

*NB! the friend declaration is only in the class definition*

# Operator overloading

Another implementation of +, using +=

## Class definition

```
class Komplex {  
public:  
    Komplex& operator+=(const Komplex& z) {  
        re += z.re;  
        im += z.im;  
        return *this;  
    }  
    // ...  
};
```

## Free function, does not need to be friend

```
Komplex operator+(Komplex a, const Komplex& b) {  
    return a+=b;  
}
```

NB! *call by value*: we want to return *a copy*.

# Conversion and increment operators

## Exempel: Counter

### Conversion to int

```
struct Counter{
    Counter(int c=0) :cnt{c} {};
    operator int() const {return cnt;}
    Counter& operator++() {++cnt; return *this;}
    Counter operator++(int) {Counter res(cnt++); return res;}
private:
    int cnt;
};
```

Note: **operator** T().

- ▶ no return type in declaration (must obviously be T)
- ▶ can be declared **explicit**
  
- ▶ two overloads for **operator++**. Dummy int parameter for postincrement.

# Static members

static members: shared by all objects of the type (like Java)

- ▶ *declared* in the class definition
- ▶ *defined* outside class definition (if not **const**)
- ▶ can be **public** or **private** (or **protected**)

# Static members

## Example: count allocations and deallocations

```
class Foo {  
private:  
    static int created;  
    static int alive;  
public:  
    Foo() {++created; ++alive;}  
    ~Foo() {--alive;}  
  
    static void print_counts();  
};
```

Definitions: *NB! without static*

```
int Foo::created{0};  
int Foo::alive{0};
```

```
void Foo::print_counts()  
{  
    cout << alive << " / ";  
    cout << created << endl;  
}
```

```
void test_lifetimes()  
{  
    {  
        Foo a;  
        a.print_counts();  
  
        Foo b;  
        b.print_counts();  
    }  
  
    {  
        Foo c;  
        Foo::print_counts();  
    }  
    Foo::print_counts();  
}
```

```
1 / 1  
2 / 2  
1 / 3  
0 / 3
```

# Static members

## Example: count allocations and deallocations

```
class Foo {
private:
    static int created;
    static int alive;
public:
    Foo() {++created; ++alive;}
    ~Foo() {--alive;}

    static void print_counts();
};
```

Definitions: *NB! without static*

```
int Foo::created{0};
```

```
int Foo::alive{0};
```

```
void Foo::print_counts()
{
    cout << alive << " / ";
    cout << created << endl;
}
```

```
void test_lifetimes()
{
    {
        Foo a;
        a.print_counts();

        Foo b;
        b.print_counts();
    }

    {
        Foo c;
        Foo::print_counts();
    }

    Foo::print_counts();
}
```

```
1 / 1
```

```
2 / 2
```

```
1 / 3
```

```
0 / 3
```

# Static members

## Example: count allocations and deallocations

```
class Foo {
private:
    static int created;
    static int alive;
public:
    Foo() {++created; ++alive;}
    ~Foo() {--alive;}

    static void print_counts();
};
```

Definitions: *NB! without static*

```
int Foo::created{0};
```

```
int Foo::alive{0};
```

```
void Foo::print_counts()
{
    cout << alive << " / ";
    cout << created << endl;
}
```

```
void test_lifetimes()
{
    {
        Foo a;
        a.print_counts();

        Foo b;
        b.print_counts();
    }

    {
        Foo c;
        Foo::print_counts();
    }
    Foo::print_counts();
}
```

```
1 / 1
2 / 2
1 / 3
0 / 3
```

# Static members

## Example: count allocations and deallocations

```
class Foo {  
private:  
    static int created;  
    static int alive;  
public:  
    Foo() {++created; ++alive;}  
    ~Foo() {--alive;}  
  
    static void print_counts();  
};
```

Definitions: *NB! without static*

```
int Foo::created{0};
```

```
int Foo::alive{0};
```

```
void Foo::print_counts()  
{  
    cout << alive << " / ";  
    cout << created << endl;  
}
```

```
void test_lifetimes()  
{  
    {  
        Foo a;  
        a.print_counts();  
  
        Foo b;  
        b.print_counts();  
    }  
  
    {  
        Foo c;  
        Foo::print_counts();  
    }  
    Foo::print_counts();  
}
```

```
1 / 1  
2 / 2  
1 / 3  
0 / 3
```

# Static members

## Example: count allocations and deallocations

```
class Foo {  
private:  
    static int created;  
    static int alive;  
public:  
    Foo() {++created; ++alive;}  
    ~Foo() {--alive;}  
  
    static void print_counts();  
};
```

Definitions: *NB! without static*

```
int Foo::created{0};
```

```
int Foo::alive{0};
```

```
void Foo::print_counts()  
{  
    cout << alive << " / ";  
    cout << created << endl;  
}
```

```
void test_lifetimes()  
{  
    {  
        Foo a;  
        a.print_counts();  
  
        Foo b;  
        b.print_counts();  
    }  
  
    {  
        Foo c;  
        Foo::print_counts();  
    }  
    Foo::print_counts();  
}
```

```
1 / 1  
2 / 2  
1 / 3  
0 / 3
```

# Suggested reading

References to sections in Lippman

Classes 2.6, 7.1.4, 7.1.5

Constructors 7.5–7.5.4

(Aggregate classes) ("C structs" without constructors) 7.5.5

Destructors 13.1.3

this and const p 257–258

inline 6.5.2, p 273

friend 7.2.1

static members 7.6

Copying 13.1.1

Assignment 13.1.2

Operator overloading 14.1 – 14.3

# Next lecture

References to sections in Lippman

Dynamic memory and smart pointers 12.1

Dynamically allocated arrays 12.2.1

Classes, resource management 13.1, 13.2

Moving objects 13.6

Type casts 4.11